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13. ABSTRACT *(Maximum 200 words)*

Local and DoD Institutional Review Boards approved the full protocol for this project; this took about 6 months and slowed the progress of this project. Data collected during this period included determination of reliability between 2- and 4-compartment body fat estimations. Volunteers included 20 active duty personnel (13 men, 7 women). Results indicated that a propagation of measurement error does not render the 4-compartment body fat estimate as any less reliable than the 2-compartment approach. Furthermore, the majority of variance observed between the 2- and 4-compartment estimates was due to between subjects differences not due to day-to-day variability. It was concluded that the 4-compartment estimate of body fat was reliable. Other data collection involved assessment of body composition on the first cohort of minority women (N=10; 7 Hispanic, 2 Pacific Islander, 1 Asian). This cohort was similar in physical characteristics to a previous database of Caucasian and African-American women. Similarly, 2- and 4-compartment estimates of body fat were similar to data collected on other groups of women. These preliminary results suggest that no racial bias exists in the Navy's equation for body fat. Data collection continues with minority women.

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FOREWORD

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IV. INTRODUCTION

All branches of the military have established standards for accession and retention (1-3). The accession standards are based on indirect determinations of body composition from weight for height (W/H) tables, while the retention standards include an assessment of a body composition based on W/H measurements and a test of aerobic fitness. Periodic review of W/H is conducted within all branches of the armed forces. Failure to meet the these standards results in anthropometric assessment and determination of percent body fat (% BF) from regression equations based on circumference measurements. However, Vogel et al (4) reported that due to difficulties encountered in predicting body density in African-American females, primarily hydrophobia, the equation selected for use with females was developed from the White population studied. *This means that for technical reasons, the population used to develop the current Army equation did not contain any minority women. This also raises the question of the appropriateness of this equation for broad use within an Army where 53% of the females soldiers are members of minority ethnic groups.*

The work outlined below proposes: to determine the accuracy and precision of the Army and Navy equations to predict percent body fat in minority and non-minority female soldiers across representative ranges of age and body fat; to develop new prediction models using a modern, nonparametric tree-structured model that will be applicable to minority and non-minority female soldiers across all ages and ranges of body fat; and to test the validity of the new prediction models using cross-validation, a computationally-intensive technique.

The results of the proposed work will provide the Armed Forces with a scientifically based litmus test of the equations currently being used to estimate %BF, to determine promotion rate and/or retention in the armed forces, and to ensure the health promotion and disease prevention of all minority and non-minority females soldiers.

V. BODY

A HYPOTHESES

1.   The Army and Navy regression equations for estimation of percent body fat apply to minority and non-minority military or military-eligible females across all applicable ranges of age and body fat with less than 5 soldiers out of 100 misclassified for retention.

2.   The agreement between the Army and Navy regression equations and the four compartment model criterion method will show an acceptable concordance correlation.

3.   The new prediction equations for estimation of percent body fat apply to minority and non-minority military or military-eligible females across all applicable ranges of age and body fat with less than 5 soldiers out of 100 misclassified for retention.

4.   The accuracy and precision of the new equations for predicting the body fat or lean body mass developed from the four compartment criterion method will be acceptable based on the concordance correlation coefficient.

B. TECHNICAL OBJECTIVES

1. To determine the accuracy and precision of the Army and Navy equations to predict percent body fat in minority and non-minority female soldiers across all ages and ranges of body fat.

2. To develop new prediction models using a modern, nonparametric tree-structured model that will be applicable to minority and non-minority female soldiers across all ages and ranges of body fat.

3. To test the validity of the new prediction models using cross-validation, a modern computationally-intensive technique.

C. PROGRESS: 98/07/01 - 99/06/30

1. A full protocol was developed specifically for body composition assessment and forwarded to the local Institutional Review Board (IRB) for approval. Local approval was granted and the protocol forwarded to Department of Defense IRB. DoD approval was granted, however, the time involved in completing this necessary task was approximately six months and thus resulted in significant delay in the data collection phase of the project.

2. Data collection during this period focused on the determination of the reliability of

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the primary methods, namely 2-compartment and 4-compartment assessment of body fat. Results for this work is present in this report.

3. Data collection was started with minority women and included a small sample of Hispanic, Asian and Pacific Islanders. Preliminary results for this work are alos present in this report.

PRELIMINARY DATA

1. Reliability of Four-Compartment Model

Reliability of the four-compartment body composition equation of Friedl et al. (1992) was assessed on 13 men and 7 women. Four-compartment body composition was assessed on each of two days within one week. In addition to calculating TEM and ICC, generalizability theory (Cronbach, 1963) was used to determine the VAR due to subjects and days main effects as well as the VAR due to subject by day interaction.

Subjects were twenty active duty Navy and Marine Corps personnel (13 men, 7 women). Ten men were Caucasian, 2 were African-American, and 1 was Hispanic. Five women were Caucasian and 2 were African-American. Subjects were informed of the risks and benefits of the study and each gave written informed consent. A Xitron 4000B bioimpedance analyzer (Xitron Technologies, San Diego, CA) was used to determine whole body resistance at 50kHz. Total body water was calculated using the gender-specific equations of Kushner and Schoeller (1986).
Whole-body bone mineral content was determined using a Hologic QDR 1500 (Hologic, Inc., Bedford, MA) dual energy X-ray absorptiometer. Total body bone mineral (TBBM) was calculated as BMC*1.0436. Residual volume was determined prior to hydrostatic weighing by the helium dilution method of Ruppel (1975) using a Modular Lung Analyzer, Model 03002 (Warren E. Collins, Inc., Braintree, MA). Weights from hydrostatic weighing were determined using a Model TI 2100 electronic scale (West Weigh Scale Co., Inc., San Diego, CA). The signal from the scale was smoothed and stable weights obtained on a PC with software developed at NHRC. Body density was calculated according to the formula of Buskirk (1961). Two-compartment body composition (SIRI BF) was estimated by the Siri (1961) equation. Four-compartment body composition (4-COMP BF) was calculated according to Friedl et al. (1992):

$$\%BF=[2.559/BD-0.734(TBW/WT)+0.983(TBBM/WT)-1.841]*100.$$

Descriptive statistics, ANOVA, and intra-class correlation coefficients (ICC) were obtained using the SPSS 8.0 statistical package for PC (SPSS, Inc., Chicago, IL). Technical error of measurement (TEM) (Pedersen and Gore, 1996) was calculated as:

$$TEM = (\text{mean square error})^2$$

Percent TEM (%TEM) was calculated as:

$$\%TEM = TEM/\text{mean}(\text{day } 1 + \text{day } 2)*100.$$

Generalizability theory (Cronbach, 1963) was used to determine VAR and % VAR due to subjects, days, and the subject by day interaction according to the procedures of Morrow (1989).

Tables 1a and 1b give subject characteristics for days 1 and 2. Table 2 gives the ICC, TEM and % TEM for SIRI BF, 4-COMP BF and variables used in the BF calculations. For

Table 1a. Subject characteristics, all subjects combined (n = 20).

	DAY 1	DAY 2
AGE (yr)	30.6±6.9	30.6±6.9
HT (cm)	171.3±10.0	171.3±9.9
WT (kg)	79.7±19.8	79.5±19.5
BMC (g)	2890±624	2919±636
TBW (l)	45.5±10.9	45.3±11.0
RV (l)	1.500±0.418	1.499±0.378
DB (g/cm3)	1.0488±0.0130	1.0503±0.0133
SIRI BF (%)	22.0±5.8	21.4±6.0
4-COMP BF (%)	21.7±5.9	21.5±5.8

Table 1B. Subject characteristics, males (n = 13) and females (n = 7).

	MALES		FEMALES	
	DAY 1	DAY 2	DAY 1	DAY 2
AGE (yr)	29.5±5.3	29.5±5.3	32.4±9.3	32.4±9.3
HT (cm)	176.0±6.7	175.9±6.8	162.6±9.4	162.7±9.4
WT (kg)	90.0±15.4	89.6±15.3	60.8±10.7	60.7±10.4
BMC (g)	3150±553	3209±535	2407±452	2407±452
TBW (l)	52.0±7.1	51.8±7.5	33.4±4.1	33.3±3.7
RV (l)	1.576±0.312	1.537±0.270	1.359±0.567	1.428±0.547
DB (g/cm3)	1.0501±0.1207	1.0514±0.0124	1.0464±0.0152	1.0481±0.0156
SIRI BF (%)	21.4±5.4	20.8±5.6	23.1±6.8	22.4±7.0

| **4-COMP BF (%)** ‖ | 20.5±5.5 | 20.4±5.5 | 23.9±6.3 | 23.5±6.4 |

HT = stature; WT = body mass; BMC = bone mineral content; TBW = total body water; RV = residual lung volume; DB = body density; SIRI BF = percent body fat by two-compartment analysis; 4-COMP BF = percent body fat by four-compartment analysis.

males, RV had the lowest ICC (0.925) and highest %TEM (5.26). RV is used in calculating DB; however, its effect on DB in males appears to be minor since the ICC and %TEM for DB are 0.976 and 0.19, respectively. There was little difference in ICC among the variables for women. SIRI BF actually had the highest % TEM for women, followed by RV and BMC.

Table 2. Intraclass correlation coefficients and technical error of measurement.

		WT	BMC	TBW	RV	DB	SIRI BF	4-COMP BF
MALES **n = 13**	ICC	0.999	0.979	0.990	0.925	0.976	0.976	0.989
	TEM	0.52kg	86.02g	0.71L	0.08L	0.002g/cm3	0.91%BF	0.56%BF
	%TEM	0.58	2.70	1.37	5.26	0.19	4.31	2.74
FEMALES **n = 7**	ICC	0.999	0.979	0.988	0.997	0.983	0.983	0.985
	TEM	0.33kg	92.53g	0.40L	0.06L	0.002g/cm3	1.0%BF	0.78%BF
	%TEM	0.54	3.87	0.59	4.00	0.21	4.37	3.29
ALL **n = 20**	ICC	0.999	0.980	0.997	0.997	0.979	0.979	0.988
	TEM	0.46kg	88.35g	0.62L	0.07L	0.002g/cm3	0.94%BF	0.64%BF
	%TEM	0.58	3.04	1.36	4.9	4.9	4.33	2.97

ICC = intraclass correlation coefficient; TEM = technical error of measurement;
%TEM = percent technical error of measurement

Table 3 gives the %VAR for SIRI BF, 4-COMP BF and variables used in the BF calculations. In most cases, greater than 97% of the VAR is due to the between subjects variability. Exceptions are RV and BMC. For RV, 7.5% of the VAR was accounted for by the subjects by days interaction for the males. For BMC, 4.9% of the VAR was accounted for by the subjects by days interaction for the females.

These data provide further evidence that, despite an increased number of measurements, propagation of error does not render 4-COMP BF less reliable than SIRI BF. In fact, TEM and % TEM were less for 4-COMP BF compared to SIRI BF for both men and women.

An examination of the effect on the estimation of 4-COMP BF of varying different variables by one TEM reveals that the single largest effect is due to TBW (0.60 % BF for males, 0.51% BF for females). DB has the second largest effect (0.47 % BF for males and 0.48 % BF for females). The effects of a one TEM difference in DB on 4-COMP BF are not as great as they are on SIRI BF (approximately 0.90% BF for a difference of 0.002 g/cm3 for males and females) due to the moderating effects of TBW and TBBM in the 4-COMP BF prediction equation. Additionally, errors in measurement of the variables used in 4-COMP BF estimation are not additive. If every variable in the 4-COMP BF equation is varied by one TEM, a difference of 0.74 % BF (males; 0.61 % BF females) is observed.

Table 3. Percent of variance due to subjects, days, and interaction.

		WT	BMC	TBW	RV	DB	SIRI BF	4-COMP BF
MALES $n = 13$	$\%\sigma^2$ S	99.9	97.5	99.0	92.3	97.4	97.4	98.9
	$\%\sigma^2$ D	0	0.4	0	0.2	0.2	0.2	0
	$\%\sigma^2$ S x D	0.1	2.1	1.0	7.5	2.4	2.3	1.1
FEMALES $n = 7$	$\%\sigma^2$ S	99.9	95.1	98.8	99.5	98.2	98.2	98.5
	$\%\sigma^2$ D	0	0	0	0.2	0.1	0.1	0
	$\%\sigma^2$ S x D	0.1	4.9	1.2	0.3	1.7	1.7	1.5
ALL $n = 20$	$\%\sigma^2$ S	99.9	98.0	99.7	96.4	97.4	97.5	98.8
	$\%\sigma^2$ D	0	0.0	0	0	0.5	0.5	0
	$\%\sigma^2$ S x D	0.1	2.0	0.3	3.6	2.1	2.0	1.2

$\%\sigma^2$ S = percent of variance due to subjects; $\%\sigma^2$ D = percent of variance due to days; $\%\sigma^2$ S x D = percent of variance due to subjects by days interaction

The great majority of the variance in 4-COMP BF (and SIRI BF) is due to between subjects variability, not day-to-day variability in measurement. RV measurement has the greatest subjects by days interaction effect in males, accounting for 7.5% of the total variance. RV measurement, like hydrostatic weighing, requires a considerable amount of subject compliance and motivation. It therefore is not surprising that there would be some slight differences in subject performance on different occasions. The women were more consistent in RV measurement from one day to the next, with more than 99% of the total variance due to subjects variability. The greatest percentage of subjects by days variance for the women was in BMC measurement (4.9%). This could have several explanations, including technician error (although the same experienced technician performed all scans), machine error, or error resulting from small movements by the subjects as they were being scanned (Cawkwell, 1998).

Conclusion

In conclusion, 4-COMP BF is highly reliable. Variables used in the estimation of 4-COMP BF can be measured with great reliability and measurement errors due to different variables are not linearly additive when estimating 4-COMP BF.

2. Validity of Circumference-Based Body Fat Estimation Equations in Minority Women

To date, data have been collected on a total of 10 women (7 Hispanic, 2 Pacific Islander, 1 Asian). Four-compartment body composition has been assessed using total body water (TBW) determined by whole body bioelectrical impedance. Respiratory water for deuterium oxide (D_2O) determination of TBW has been collected, with analysis pending.

Although numbers are currently too small for meaningful statistical comparisons, descriptive statistics are given in Table 4 for the 10 women of Hispanic, Pacific Islander, or Asian ethnicities. Also included are the same statistics for the 150 Caucasian and 120 African-American women in the data base. Mean values for the three groups are similar, with means for the Hispanic/Pacific Islander/Asian group falling between those for Caucasians and African-Americans for body mass, 4-compartment body fat percentage, and Navy circumference equation (NAVY BF) body fat percentage.

Table 4. Descriptive statistics.

	H, PI, A	C	A-A
Age	28.8 ± 4.1	31.0 ± 7.5	29.4 ± 6.8
HT (cm)	163.4 ± 6.8	164.2 ± 6.8	165.4 ± 6.1
WT (kg)	67.5 ± 7.5	66.9 ± 10.7	70.8 ± 10.4
4-COMP BF (%)	28.9 ± 5.8	28.5 ± 6.6	30.3 ± 6.9
NAVY BF (%)	31.0 ± 5.5	30.4 ± 6.3	31.8 ± 6.5

Values are means plus or minus standard deviations. H, PI, A = Hispanic, Pacific Islander, Asian; C = Caucasian; A-A = African-American; HT = stature; WT = body mass; 4-COMP BF = four-compartment body fat; NAVY BF = Navy circumference equation body fat.

Table 5. Percent body fat.

RACE	4-COMP BF	NAVY BF	Difference
Hispanic	32.09	39.99	-7.90
Hispanic	21.74	25.51	-3.77
Hispanic	36.05	34.97	1.08
Asian	35.39	36.24	-0.85
Hispanic	30.03	32.01	-1.98
Pacific islander	26.95	27.39	-0.44
Hispanic	17.65	21.45	-3.80
Hispanic	30.89	32.12	-1.23

Pacific islander	26.68	28.29	-1.61
Hispanic	31.58	31.68	-0.10

Table 5 gives individual values for 4-COMP BF and NAVY BF estimations. In most cases, the two body fat estimations agree reasonably well. In one case, there is a 7.9% difference between the two body fat estimations. While extreme, differences of this magnitude have occurred among the Caucasian and African-American women that have been tested at Naval Health Research Center. There is, therefore, no reason to believe that this one case of an extreme difference in body fat estimation in an Hispanic woman indicates racial bias.

Conclusion

In conclusion, too little data is presently available to determine whether or not a racial bias for Hispanic, Pacific Islander, or Asian women exists for body fat estimation by the Navy's circumference equation. Early results are comparable to those seen in Caucasian and African-American women for whom a racial bias in the Navy's equation does not exist.

KEY RESEARCH ACCOMPLISHMENTS

♦ Completion and approval of Institutional Review Board human subjects protocol.

♦ Completion of 2- and 4- compartment model reliability.

♦ Initiation of data collection on minority women. Preliminary results suggest no racial/ethnic bias in prediction equations based on a large data base.

REPORTABLE OUTCOMES

♦   Kujawa, K.I., reading, J.E., Glover, W.L., Hodgdon, J.A. Reliability of a four-compartment body fat estimation technique. Med Sci in Sports & Exer 31: S203, 1999. (Abstract).

CONCLUSIONS

The majority of the variance in 4-COMP BF (and SIRI BF) is due to between subjects variability, not day-to-day variability in measurement. RV measurement has the greatest subjects by days interaction effect in males, accounting for 7.5% of the total variance. RV measurement, like hydrostatic weighing, requires a considerable amount of subject compliance and motivation. It therefore is not surprising that there would be some slight differences in subject performance on different occasions. The women were more consistent in RV measurement from one day to the next, with more than 99% of the total variance due to subjects variability. The greatest percentage of subjects by days variance for the women was in BMC measurement (4.9%). This could have several explanations, including technician error (although the same experienced technician performed all scans), machine error, or error resulting from small movements by the subjects as they were being scanned (Cawkwell, 1998). In conclusion, 4-COMP BF is highly reliable. Variables used in the estimation of 4-COMP BF can be measured with great reliability and measurement errors due to different variables are not linearly additive when estimating 4-COMP BF.

The data presently available from minority individuals is too limited to determine whether or not a racial bias for Hispanic, Pacific Islander, or Asian women exists for body fat estimation by the Navy's circumference equation. However, early results are comparable to those seen in Caucasian and African-American women for whom a racial bias in the Navy's equation does not exist.

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APPENDICES

A. Reliability of a four-compartment body fat estimation technique (Abstract and Poster Paper).

Annual Meeting Abstracts

**American College
of Sports Medicine**
46th Annual Meeting
Washington State
Convention & Trade Center
June 2-5, 1999

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933 RELIABILITY OF A FOUR-COMPARTMENT BODY FAT ESTIMATION TECHNIQUE

K. L. Kujawa, J. E. Reading, W. L. Glover, and J. A. Hodgdon (FACSM) (Sponsor: J. A. Hodgdon, FACSM)

Preliminary data on reliability of a four-compartment body composition model (Friedl et al., Am. J. Clin. Nutr. 55:764-70, 1992) are presented. Ten active-duty U.S. Navy personnel (7 men, 3 women; 33.9 ± 7.5 years of age; stature 174.9±8.4 cm; weight 87.0±19.9 kg) were tested twice within one week. Measurements included bone mineral content (BMC) by DXA (Hologic 1500), total body water (TBW) by bioimpedance (Kushner and Schoeller, Am. J. Clin. Nutr. 44:417-424, 1986), residual lung volume (RV) by helium dilution, and hydrostatic weighing (HYDRO). Two-compartment body fat (SIRI BF) was calculated from body density (DB) using the Siri equation. Four-compartment body fat (4-COMP BF) was calculated as: $[2.559/DB - 0.734(TBW/weight) + 0.983(BMC/weight) - 1.841]*100$. Mean SIRI BF percent was 22.5±2.22% and 22.5±2.18% for days 1 and 2; means for 4-COMP BF were 22.4 ± 2.28% and 22.6 ± 2.29%. Mean values for BMC were 3062.80±169.8 g and 3153.18±167.9 g; TBW 48.85±3.38 L and 48.59±3.43 L; RV 1.752±.07 L and 1.708±.07 L; and DB 1.048±.005 g/cm³ and 1.048±.005 g/cm³. Intraclass correlation coefficients (ICC) and technical error of measurement (TEM) were determined from ANOVA between day one and day two values. TEM was calculated as: $TEM = (mean\ square\ error)^{1/2}$ and percent TEM (%TEM) was calculated as: $\%TEM = TEM/mean(day1 + day2)*100$.

	BMC	TBW	RV	DB	SIRI BF	4-COMP BF
ICC	0.957	0.999	0.861	0.990	0.990	0.994
TEM	122.77g	0.37L	0.09L	0.001g/cc	0.65%BF	0.54%BF
% TEM	3.9	0.08	5.2	0.1	2.9	2.4

In conclusion, ICC was slightly higher and TEM slightly lower for 4-COMP BF compared with SIRI BF. Reliability of 4-COMP BF, therefore, compares favorably to SIRI BF reliability, confirming the work of Friedl et al. (1992).

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